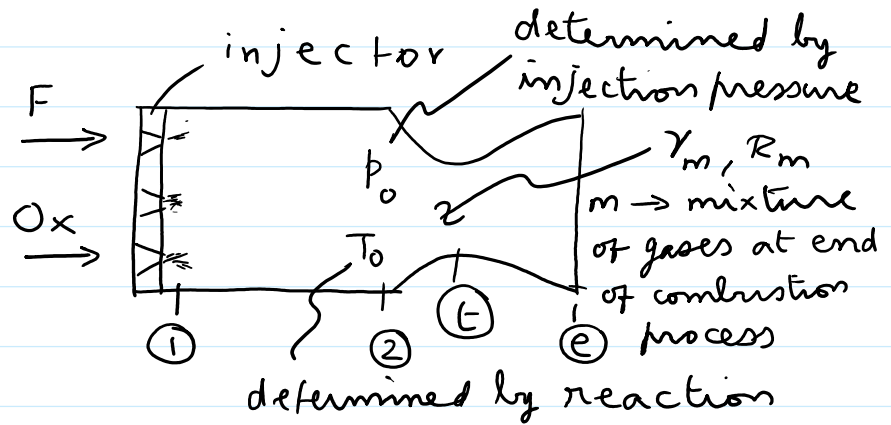


* A LPRE Thrust chamber requires propellant feed at high pressure. Unlike in the SRM, there is no increase in p_0 in the combustion chamber.



Recall : $\bar{M}_m = \sum X_i \bar{M}_i$, $\bar{c}_{p,m} = \sum X_i \bar{c}_{p,i}$, $\gamma_m = \frac{\bar{c}_{p,m}}{\bar{c}_{p,m} - \bar{R}}$

For the mixture, $R_m = \frac{\bar{R}}{\bar{M}_m}$

Ex

An ideal hydrogen-oxygen rocket thrust chamber has $r = 5$. Fuel (H_2) and oxidizer (O_2) are injected at 68 atm, and 298.15 K. The temperature (T_0) and the composition (mole fractions X_i) of the product mixture are given in Table 12.2. Assuming fully-expanded jet at SL, calculate I_{sp} . $\gamma_{MON} = 1.67$, $\gamma_{DI} = 1.29$, $\gamma_{TRI} = 1.17$

COCKET PROPELLANTS COMBUSTION AND EXPANSION

per mole of H_2O . For excess oxygen reacting $H_2 + mO_2$, where m can have any positive value by

$$\frac{p_0}{p} = \left(\frac{p_0}{p} \right)^{\frac{\gamma_m}{\gamma_m - 1}} \quad (12.1b)$$

used by Eqs. (12.1) is shown in Fig. 12.1 as a γ - p diagram. The stoichiometric value of r is 8, and Eq. (12.1b) when $r = 8$, the two equations (12.1) show that if the combustion reaction of the fuel-air ratio would be stoichiometric, all if we employ the more realistic equilibrium (12.1) show the results of specific-impulse calculation. The product composition, specific-impulse, and γ have been determined by methods discussed in (11.3), by using a

owing to dissociation, the oxidizer-fuel ratio is for maximum specific impulse. The difference between the "complete combustion" calculation (Eqs. 12.1) calculation is largely due to the reduced γ in partially dissociated. This effect becomes more important as the stoichiometric ratio and the combustion high dissociation usually results in slightly important effect is that of reduced energy

TABLE 12.2 EQUILIBRIUM COMPOSITION

TABLE 12.2 Equilibrium gas composition, reactants at 298.15 K

Fuel	H_2	H_2	N_2H_4	N_2H_4	CH_3OH
Oxidizer	O_2	O_2	O_2	O_2	O_2
Oxidizer-fuel mass ratio	5	5	0.95	0.95	2.58
Pressure	6.89	10.34	6.89	10.34	6.89
MPa	1000	1500	1000	1500	1000
Temperature	3429	3466	3410	3403	3676
Mole fractions					
H_2	0.3607	0.3625	0.0211	0.0197	0.006
O_2	9.97×10^{-4}	9.79×10^{-4}	0.0218	0.0198	0.009
H_2O	0.5744	0.5799	0.8473	0.8501	0.936
OH	0.0206	0.0218	0.0766	0.0756	0.060
O	0.0015	0.0015	0.0012	0.0015	0.001
H	0.0063	0.0034	0.0067	0.0075	0.006
N_2			0.001	0.001	
NO			0.001	0.001	
N			9.97×10^{-4}	1.12×10^{-3}	
CO			9.97×10^{-4}	9.97×10^{-4}	
CO_2					0.009

the mixture enthalpy. The stoichiometric oxidizer-fuel mass ratio for $CH_3OH + nO_2$ is $n = 2.58$, which is 17% below the fuel-rich, and not very useful.

$p_0 = 68 \text{ atm} = 68(0.101325) = 6.89 \text{ MPa}$

From Table 12.3,

$$T_0 = 342.9 \text{ K}$$

$$x_{\text{H}_2} = 0.3607, x_{\text{O}_2} = 0.977(10^{-3}), x_{\text{H}_2\text{O}} = 0.5744,$$

$$x_{\text{OH}} = 0.0260, x_{\text{O}} = 0.0015, x_{\text{H}} = 0.0363$$

$$\{\bar{M}_{\text{H}} = 1, \bar{M}_{\text{O}} = 16\}$$

$$\begin{aligned} \bar{M}_m = \sum(x_i \bar{M}_i) &= 0.3607(2) + 0.977(10^{-3})(32) + 0.5744(18) + 0.0260(17) + \\ &\quad 0.0015(16) + 0.0363(1) = 11.59 \end{aligned}$$

$$R_m = \frac{\bar{R}}{\bar{M}} = \frac{8314.3}{11.59} = 717.4 \frac{\text{J}}{\text{kg-K}}$$

$$\bar{c}_{pm} = \sum(x_i \bar{c}_{pi})$$

$$\bar{c}_{p_{\text{H}}} = \bar{c}_{p_{\text{O}}} = \frac{\gamma_{\text{MON}} \bar{R}}{\gamma_{\text{MON}} - 1} = 2.493 \bar{R}$$

$$\bar{c}_{p_{\text{H}_2}} = \bar{c}_{p_{\text{O}_2}} = \bar{c}_{p_{\text{OH}}} = \frac{\gamma_{\text{DI}} \bar{R}}{\gamma_{\text{DI}} - 1} = 4.448 \bar{R}$$

$$\bar{c}_{p_{\text{H}_2\text{O}}} = \frac{\gamma_{\text{TRI}} \bar{R}}{\gamma_{\text{TRI}} - 1} = 6.882 \bar{R}$$

$$\bar{c}_{pm} = \sum(x_i \bar{c}_{pi}) = 5.772 \bar{R}$$

$$\gamma_m = \frac{\bar{c}_{pm}}{\bar{c}_{pm} - \bar{R}} = \frac{5.772 \bar{R}}{5.772 \bar{R} - \bar{R}} = \frac{5.772}{4.772} = 1.21$$

Calculation of I_{sp} is as discussed earlier (ch 11)

$$p_{0e} = p_0 = 68 \text{ atm}$$

$$p_e = p_a = 1 \text{ atm}$$

↖ ↗ sea level
fully expanded

$$\frac{p_{0e}}{p_e} = \frac{68}{1} = 68$$

$$\left(1 + \frac{\gamma_m - 1}{2} M_e^2\right)^{\frac{\gamma_m}{\gamma_m - 1}} = 68 \Rightarrow M_e = 3.21$$

$$T_{0e} = T_0 = 3429 \text{ K}$$

$$T_e = \frac{T_{0e}}{1 + \frac{\gamma_m - 1}{2} M_e^2} = 1647 \text{ K}$$

$$u_e = M_e \sqrt{\gamma_m R_m T_e} = 3.21 \sqrt{(1.21)(717.4)(1647)}$$
$$= 3838 \text{ m/s}$$

$$u_{eq} = u_e + \underbrace{\frac{RT_e}{u_e} \left(1 - \frac{p_a}{p_e}\right)}_0 = u_e = 3838 \text{ m/s}$$

$$I_{sp} = \frac{u_{eq}}{g_e} = \frac{3838}{9.81} = 391 \text{ s}$$

$$\frac{A_e}{A_t} = \frac{A_e}{A_e^*} = \frac{1}{M_e} \left[\frac{2}{\gamma_m + 1} \left(1 + \frac{\gamma_m - 1}{2} M_e^2\right) \right]^{\frac{\gamma_m + 1}{2(\gamma_m - 1)}} = 8.73$$